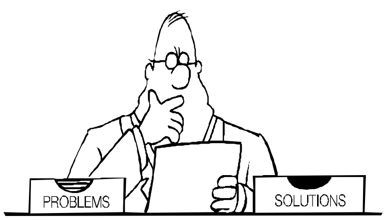
UNIT 5:

Introduction to Radiation
Health Effects of Radiation

Understanding Radiation—Getting the Essential Concepts



You have just gained a basic awareness of how hazardous materials incidents can affect your involvement and hospitals' involvement in responding to such incidents. As you learned, radioactive materials are just one type of hazardous material. However, there are some basic concepts you need to understand about radiation and radioactive materials. These basic concepts will provide a solid foundation for taking additional course work in responding to radiation-related hazardous events and will prepare you for the classroom course on managing radiation accidents.

Overview

This unit identifies sources of radiation and presents data on the frequency of radiation accidents. It describes the types of radiation injuries and provides an overview of radiation physics. This unit also describes how to measure radioactivity and the types of instruments used to measure it, defines some basic radiation protection principles, and presents the recommended radiation exposure limits. It also covers basic biophysical and biological effects of ionizing radiation, to provide a foundation for understanding the clinical aspects of radiation injuries.

Objectives

At the end of this unit, you will be able to:

1. Identify sources of radiation.
2. State the prevalence of radiation accidents.
3. Identify types of radiation injuries and differentiate among them.
4. Define ionizing radiation.
5. Explain the differences among the various types of ionizing radiation in terms of penetrating power and effects on living tissue.
6. Define the terms curie, rem, rad, roentgen, and their SI units.
7. State four radiation protection principles and explain their use in reducing radiation exposure.
8. State the use and limitations of the survey meters and dosimeters.
9. Describe methods of contamination.
10. Establish patient management priorities.
11. List practical ways of reducing radiation exposure.
12. Define the effect chemicals may have on a radiation-contaminated patient.
13. Describe the dose-response relationship and its clinical effects.
14. Describe the routes by which any hazardous substance may enter the body.
15. Describe the organ systems that may be affected in the contaminated or exposed patient.
16. Distinguish between stages of acute radiation syndrome.
17. State the nature of radiological and chemical hazards.
18. Summarize the toxic effects of some radioisotopes.

Pretest

If you think you have the requisite skills and knowledge for this topic area, take the pretest on the next page. If you score 85 percent or higher, you can skip this unit. However, this unit is recommended because it will prepare you for the classroom course that deals primarily with managing radiation incidents.

UNIT 5: PRETEST

Directions: Answer each question. Each answer counts 20 points. After you have completed the test, check your answers in Appendix B.

1. Can incorporation occur without contamination? Explain your answer.

2. What are the three most common types of ionizing radiation?

3. What is the most penetrating type of ionizing radiation?

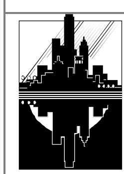
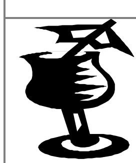
4. List two units of quantity of measuring radioactivity.

5. List three elements of radiation protection.

Introduction to Radiation Accidents

Sources of Radioactive Materials

Radiation comes from outer space, the ground, and even from within our own bodies. Radiation is all around us and has been present since the birth of this planet. Radiation occurs naturally and in man-made sources. The table below shows some other sources of radiation.

Sources of Radioactive Materials	
Radiation Source	**Relative Dose (Millirem)**
Gastrointestinal series (upper and lower)	1,400 millirem
 Radon in average household in the U.S.	200 millirem annually
Living in Denver	81 millirem annually
X-rays and nuclear medicine	50 millirem annually
Natural radioactivity in the body	39 millirem annually
 Living in Chicago	34 millirem annually
Cosmic radiation	31 millirem annually
Mammogram	30 millirem
Living at sea level	28 millirem annually
 Consumer products (such as drinking water)	11 millirem annually
Chest x-ray	10 millirem
Living near a nuclear power station	less than 1 millirem annually

Radiation used in medicine is the largest source of man-made radiation to which we are exposed. Most of our exposure is to diagnostic x-rays—Americans receive 200 million x-rays every year. Radiation is also used in cancer treatments. One-third of all successful cancer treatments involve radiation.

Nuclear power plants use radioactive materials (uranium or plutonium) to generate electricity, and any activity that uses radioactive materials generates radioactive waste. Mining, nuclear power, defense, nuclear medicine and scientific research all produce radioactive waste that must be disposed of properly.

Frequencies and Prevalence of Radiation Accidents

Radiation accidents do occur, though their number and frequency vary. Fortunately, few radiation accidents pose life-threatening hazards because of the many control procedures and mechanisms that are in place. However, when these controls fail, the results can be devastating and often fatal.

Number of Accidents, Exposures, and Fatalities

Radiation accidents can occur at biological firms, medical offices, hospitals, industrial labs, nuclear power plants, military installations and transportation routes (land, sea, air).

Medical Misadministrations

The Nuclear Regulatory Commission and Agreement States reported the following medical misadministration related incidents for radiation during January 1, 1994 through September 30, 1995. As shown in the table below, the majority of the misadministrations involved brachytherapy treatment; sodium iodide procedures were the second highest. Misadministrations involving dose variances during brachytherapy and sodium iodide treatments most often result in an overdose rather than an underdose. Teletherapy and gamma stereotactic radiosurgery were exclusively overdoses.

These problems occurred for the following reasons: communication problems due to misunderstanding the physician's request, not following the quality management plan, and not properly documenting changes to the treatment plan. Human error problems included incorrect calculation of the treatment plan and errors in operating the equipment.

Medical Misadministrations Reported by NRC (1994-1995)	
Procedure	**Number**
Diagnostic radiopharmaceutical	1
Sodium iodide radiopharmaceutical	14
Brachytherapy	42
Teletherapy	12
Gamma Stereotactic Radiosurgery	1
TOTAL	**69**
Source: Annual Report, 1994-FY 95, Nuclear Materials, Office for Analysis and Evaluation of Operational Data, U.S. Nuclear Regulatory Commission	

Radiation Exposures

Over 80 percent of our exposure to radiation comes from natural sources. Fifty-five percent of our exposure to natural sources of radiation usually comes from radon. Radon is a colorless, tasteless, and odorless gas that comes from the decay of uranium found in nearly all soils. Our own bodies, which contain and concentrate the radioactive element potassium, account for 11 percent of our total exposure. Another three percent of our exposure to radiation comes from consumer products. The average annual radiation exposure for persons living in the United States is 360 millirem.

There were some radiation overexposures reported also, as listed in the table below.

Radiation Overexposures Reported by NRC (1994-1995)	
Type of Licensee	**Number of Individuals**
Medical/Academic	4
Research/Commercial	37
Industrial Radiography	16
TOTAL	**57**
Source: Annual Report, 1994-FY 95, Nuclear Materials, Office for Analysis and Evaluation of Operational Data, U.S. Nuclear Regulatory Commission	

The primary causes of medical/academic and research/commercial overexposures included failure to ensure that adequate dosimetry was issued and monitored, failure to wear adequate protective clothing in areas containing discrete radioactive particles, and failure to follow procedures. The primary causes of industrial radiography exposure were failure to conduct the required radiation surveys, failure to set up or monitor radiation boundaries, failure to follow established emergency procedures, and lack of adequate supervision of assistants.

Radioactive Alerts

NRC-licensed nuclear materials facilities reported the following alerts in 1994 and 1995.

Radioactive Alerts Reported by NRC (1994-1995)		
Facility	**Description**	**Duration**
Westinghouse (Fuel Facility)	Uranium hexafluoride release	2 hours, 35 minutes
Allied-Signal (Fuel Facility)	Leak of uranium hexafluoride from a loose cylinder connection into the feed material building	50 minutes
Babcock & Wilcox (Fuel Facility)	Plant evacuation due to a nitric acid spill	3 hours, 5 minutes
Source: Annual Report, 1994-FY 95, Nuclear Materials, Office for Analysis and Evaluation of Operational Data, U.S. Nuclear Regulatory Commission		

Radiation Accidents Requiring Hospital Emergency Services

The following are representative examples of radiation accidents that require hospital emergency services.

1. Goiania, Brazil
   In 1985, a private radiotherapy clinic moved to a new location and abandoned a Cs-137 radiotherapy unit. Two people found the abandoned unit and took it home, not knowing what it was but believing that it had some scrap value. While attempting to dismantle it, they broke open the source capsule, releasing the Cs-137 that was in the form of a soluble chloride salt, heavily contaminating the premises. The unit with the ruptured capsule was sold to a junkyard owner for scrap. He noticed that the capsule glowed blue in the dark, and had people come and see this and distributed pieces of the Cs-137 salt to friends and family members. Several people became ill with gastrointestinal symptoms, but did not connect it to the source. One person did make the connection, and took the capsule to the public health department. Twenty people were identified as needing hospital treatment; four died within 4 weeks of the exposure, and their doses were estimated from 4.5 to 6 Gy. One hundred twelve thousand people were monitored for contamination, and 249 were found to be contaminated externally and/or internally—some quite heavily. In addition, the environment was heavily contaminated and required extensive decontamination, producing more than 275 truckloads of waste estimated to contain 1,200 Ci of Cs-137.

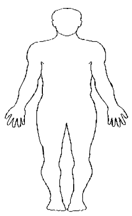
2. Springfield, Massachusetts
   On December 16, 1991, a truck carrying new fuel from Wilmington, North Carolina to Yankee Nuclear Power Station in Vernon, Vermont, was involved in an accident when it collided with a car traveling in the wrong direction. The truck and radioactive material were engulfed in flames. The truck drivers were transported to the hospital by ambulance unattended due to concerns over contamination. The hospital was informed enroute of the possibility of contamination with radioactive material, but did not receive detailed information until about one-half hour after arrival. The patients were taken to the decontamination room, were examined and found to be uncontaminated, and were treated for minor injuries and released. The driver of the car was also transported, found to be uncontaminated, treated and released. The fire was allowed to burn itself out. The fuel containers did not breach, and no environmental contamination was found.

Do you know what type of radiation accidents your facility has responded to in the last year?

Types of Radiation Injuries

There are three types of radiation injuries: external irradiation, contamination, and incorporation.

External Irradiation occurs when all or part of the body is exposed to penetrating radiation from an external source. A similar thing occurs during an ordinary chest X-ray. *A person who has been exposed to radiation from an external source, but has not been contaminated by the radioactive material, is NOT radioactive and presents no danger to caregivers.*



Whole Body (total) exposure occurs when the entire body is irradiated more or less uniformly from an external source. In addition, when a radioactive material is uniformly distributed throughout the body tissues rather than being concentrated in certain organs, the irradiation can be considered whole-body exposure as well as the patient being contaminated.

Local exposure occurs when a radioactive material is concentrated in certain organs or body parts, or when a local portion of the body is irradiated, such as a hand.

External Contamination means that radioactive materials in the form of gases, liquids or solids are released into the environment and contaminate people externally, such as on skin and clothing. This type of contamination is the easiest to remove.

Internal Contamination refers to radioactive materials being taken up into the body, and being contained in the gut, lungs and blood or extracellular fluids. This requires the radioactive materials to enter through a ‘portal of entry’ such as the mouth, nose, eyes, wounds or other skin breaks. The vagina and anus can also serve as portals of entry if the mucosa becomes contaminated. Intact skin forms a good barrier to most forms of radioactive materials.

Incorporation refers to the uptake of radioactive materials by body cells, tissues and target organs such as bone, liver, thyroid or kidney. Radioactive materials are distributed throughout the body based on their chemical properties. Incorporation cannot occur unless contamination has occurred. Incorporation can occur rapidly, within as little as an hour or less. This is the most difficult type of contamination to remove. Radioisotopes have chemical properties identical to their stable counterparts. For example, a thyroid cell will take up radioactive I-131 and use it to make thyroid hormone just as it would stable I-127. The cell will be unable to tell the difference until the I-131 decays to Xe-131, emitting a beta particle and gamma radiation.

Exercise: Identifying Types of Radiation Injuries

Purpose: To assess your understanding of the types of radiation injuries.

Directions: Answer each question. You can check your answers in Appendix B. If you missed any, review this section before continuing.

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1. Mary had a series of x-rays taken during her visit to the emergency room. What type of radiation exposure did she receive?

2. Jim spilled a radioactive material on his skin. Is Jim exposed, contaminated or both?

3. Three school children accidentally picked up an unbroken, sealed container that had dropped off a truck that was carrying radioactive materials. Is it possible that they could experience incorporation? Why or why not?

4. Will these children be radioactive or dangerous to care for?

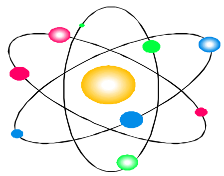
Radiation Physics

A fundamental knowledge of atomic structure and matter is helpful in understanding radioactivity.

Atomic Structure

Elements are substances that cannot be broken down into simpler substances by any chemical means. There are 105 known elements, each with specific characteristics. The atom is the simplest unit into which an element can be divided and still retain the specific properties of the original element. Molecules are combinations of two or more atoms. Molecules can be as small as 2 atoms such as O_2, or as large as proteins that may contain thousands of atoms. Each element is identified by a one- or two-letter symbol, such as O for oxygen, He for helium, Pb for lead, etc.

Atoms



An **atom** is composed of a central nucleus, containing most of its mass, and electrons orbiting in shells around the nucleus. The nucleus consists of a number of fundamental particles, including protons and neutrons. The number of protons determines the type of atom or the element (hydrogen, oxygen, etc.) and also equals the atomic number. Some atoms are stable while others are unstable. Unstable atoms attempt to stabilize by emitting energy and particles from their nuclei in the form of ionizing radiation. Atoms that emit ionizing radiation are radioactive. Electrons have a negative electrical charge, protons have a positive charge, and neutrons carry no charge.

Neutrons

The neutron is an uncharged particle having a mass similar to that of a proton, approximately equal to the masses of a proton and an electron. They interact directly with atomic nuclei. Because of their mass and energy, neutrons can cause severe disruptions in atomic structure. (In addition, they have the ability to convert stable isotopes to radioisotopes.) Neutron radiation is significant mainly in nuclear fuel, weapons and research types of facilities.

Ions

Atoms are electrically neutral when the number of negatively charged electrons orbiting the nucleus equals the number of positively charged protons within the nucleus. When the number of electrons is greater than or less than the number of protons in the nucleus, the atoms are not electrically neutral and carry a net negative or positive charge, respectively. At this point they are called **ions** and tend to combine with other ions of opposite net charge to form a neutral molecule.

Ionizing Radiation

Ionizing radiation is radiation that can produce charged particles (ions) in any material it strikes. These charged particles can cause damage to molecules, cells, or tissues. The three most common types of ionizing radiation are alpha particles, beta particles, and gamma rays.

Radiation Energy. Each type of radiation can be emitted with various levels of energy, measured in eV (electron volts). Due to the magnitude of the numbers, energies are usually expressed in KeV (thousands) and MeV (millions).The type of radiation and its energy are unique to the type of radioactive material and can be used to identify it.

Alpha (α) Particles

Alpha particles are positively charged particles consisting of two protons and two neutrons all strongly bound together by nuclear forces. They are the heaviest of the radioactive particles. Alpha particles have a mass about 7000 times the mass of electrons and are ejected from the nuclei of radioactive atoms with one or several characteristic and discrete energies. Alpha particles are the least penetrating of the three types of ionizing radiation. They do not penetrate the dead layer of skin and can be stopped by a piece of paper or clothing. They are, however, not a “safe” type of radiation. They are energetic particles that transfer their energy over a short distance, doing a great deal of damage. A health hazard may occur when alpha-emitting materials are inhaled or swallowed, or enter the body through a wound, depositing themselves near or in cells where the energetic alpha particles will do extensive damage when released. Thus, alpha particles are essentially an internal hazard only.

Beta (β) Particles

Beta particles are high-speed, charged particles with a moderate penetrating power. These particles have the characteristics of electrons, and are negatively charged. Beta particles can travel several hundred times the distance of alpha particles in the air and can penetrate into skin and cause severe skin burns. They require fairly thin (a few millimeters) shielding such as thin metal, wallboard or heavy clothing to stop them. Thus, beta particles can be an external and an internal hazard because they can injure from both the outside and inside of the body.

Gamma (γ) Rays

Gamma rays are electromagnetic radiation emitted from the nucleus of a radioactive atom. Gamma rays are the most penetrating type of radiation and can travel many meters to miles in air and deeply into tissue, doing damage to deep organs. Because gamma rays can travel through the body, they are sometimes referred to as “penetrating radiation.” Like emitters of beta particles, gamma rays constitute an internal and an external hazard.

Neutrons

The neutron is an uncharged particle having a mass similar to that of a proton, approximately equal to the masses of a proton and an electron. They interact directly with atomic nuclei. Because of their mass and energy, neutrons can cause severe disruptions in atomic structure. (In addition, they have the ability to convert stable isotopes to radioisotopes.) Neutron radiation is significant mainly in nuclear fuel, weapons and research types of facilities.

Isotopes and Nuclides

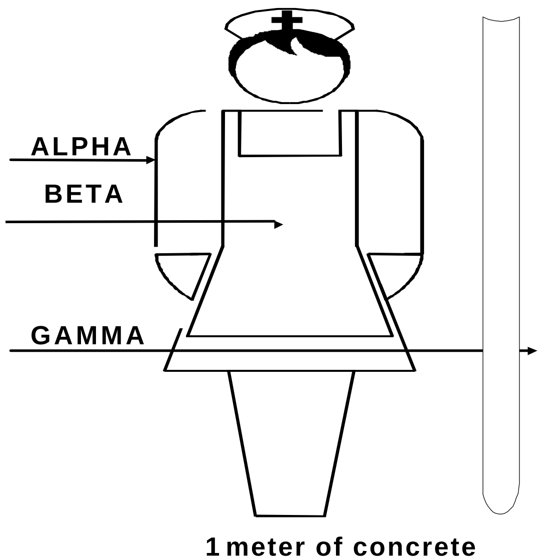
Isotopes are forms of the same element that differ by the number of neutrons in the nucleus. Since they are the same element, they have the same number of protons, and thus the same atomic number. Since the number of neutrons is different, the atomic mass number (number of protons + neutrons) will be different, and is how the isotope is identified. For example, hydrogen has three isotopes, with one, two, and three atomic mass units (one proton each, plus 0, 1 and 2 neutrons, respectively). H-1 is ‘normal’ hydrogen; H-2 and H-3 are commonly called deuterium and tritium, respectively. The first two of these are stable (nonradioactive), but tritium is a radioactive isotope. Isotopes are identified by their symbol and mass number, as in H-2, etc. They can also be written as hydrogen-2, or ^{2}H. The atomic number may also be included as a subscript $^{2}H_{1}$.

The central core of an atom is the **nucleus** and contains nearly all of the atom’s mass. Different types of nuclei are called **nuclides**. For example, the nucleus of an I-131 atom is called its nuclide. In common use, isotope and nuclide can be used interchangeably. A nuclide is characterized by its mass number as well as its atomic number.

The terms “radioisotope” and “radionuclide” merely denote the radioactive forms.

Radioactive Decay

Radioactive decay is a process whereby an unstable nucleus attempts to stabilize through the emission of energetic particles (alpha, beta, neutron) and/or pure energy (gamma). Emission of an alpha particle results in the loss of 2 neutrons and 2 protons. This results in a new element being produced because these particles are being ejected from the nucleus. These new atoms are called “daughters.” Sometimes they are successful in producing a stable atom. Sometimes, however, several decays are needed to produce a stable daughter, as in the decay of Uranium (U) that will undergo over 10 decays before it finally becomes stable lead (Pb). Every decay produces a new daughter. The following diagram illustrates the penetrating power of the different types of radiation.



Penetrating Power of Radiation

<u>Alpha</u> can be stopped by your skin and clothing.

<u>Beta</u> can be stopped by your clothing but can penetrate your skin and cause heat burns.

<u>Gamma</u> is the most penetrating and can travel through the body.

Measuring Radioactivity

When dealing with radiation, it is important to know how much radiation is present and the extent of exposure over a period of time. Radioactivity is measured in units of quantity, as described below.

Units of Quantity (Amount) of Radioactive Material

Different radioactive materials emit very different amounts of radiation. Thus, conventional units of mass or weight such as the kilogram or pound do not relate to the amount of radiation being emitted from a sample of radioactive material and are not effective units to measure quantity. The **curie (Ci)** measures the amount of radioactive material based on the amount of radiation emitted and allows better comparison of different types of radioactive materials. One curie of radioactive material is defined as the amount of radioactive material undergoing 37 billion decays per second, regardless of it's mass.

The international system of units is based on the meter (length), kilogram (mass), and the liter (volume), and is known as **Systems International (SI).** The SI unit corresponding to the curie is the SI unit of the Becquerel (Bq), and is defined as an amount of radioactive material undergoing 1 decay per second.
1 Ci = 37 GBq

Millicurie (mCi). One thousandth of a curie.

Microcurie (µCi.). One millionth of a curie.

Megabecquerel (MBq). One million Bq.

Gigabecquerel(GBq) One billion Bq.

Units of Absorbed Dose

Dose means the total amount of radiation or energy absorbed. **Absorbed Dose** is the energy imparted to matter by ionizing radiation per unit mass of irradiated material. The t**otal dose** = dose rate x exposure time. For example, 25 R/hr (dose rate) x 1/2 hour (exposure time) = 12.5 R (total dose).

Exposure (Dose) Rate

The exposure (dose) rate is the amount of radiation exposure per unit of time, usually per hour. The exposure rate is generally expressed in roentgens per hour or in milliroentgens per hour on most of the instruments in common use.

Radiation Absorbed Dose (Rad). Rad is a measure of the energy deposited in matter by ionizing radiation or, in other words, an indication of how much immediate damage radiation causes to matter.
The SI Unit is the **Gray (Gy**). 1 Rad = 0.01 Gy, or 100 Rad = 1 Gy.

Units of Exposure

Roentgen (R). The roentgen is a measure of how much charge due to ionization is produced in a volume of air by X and gamma radiation only. The SI unit is the Coloumb/kg. It is not currently in widespread use.

Roentgen equivalent man (rem). Rem is a measure of the amount of biological damage caused by radiation passing through human tissue. Different types and energies of radiation are capable of causing different degrees of damage. For example, alpha radiation is more capable of causing biological damage to the tissues that it interacts with than is gamma radiation. The rem attempts to give an easy way of equating the ability to cause biological damage. Rem is calculated by multiplying Rad by a factor that accounts for the differing abilities to cause damage.

The SI unit is the **sievert (Sv**). 1 rem = 0.01 Sv or 100 rem = 1 Sv.

The sievert (Sv) and rem are health effects-related measurements of absorbed radiation.

Exposure (Dose) Rate

The exposure (dose) rate is the amount of radiation exposure per unit of time, usually per hour. The exposure rate is generally expressed in roentgens per hour or in milliroentgens per hour on most of the instruments in common use.

Exercise: How Well Do You Know Your Physics?

Purpose: To assess your understanding of basic radiation physics.

Directions: Answer each item. Check your answers in Appendix B. If you missed any items, review this section before continuing on to the next section.

1. How do unstable atoms become stable?

2. Which type of ionizing radiation is the least penetrating?

3. What is the SI unit that measures the amount of radioactive material?

4. What is the unit for radiation absorbed dose in SI units?

5. What are two biological effects units of absorbed radiation?

Radiation Protection Principles

Elements of Radiation Protection

ALARA

This principle states that all efforts be aimed at keeping the radiation exposure **As Low As Reasonably Achievable.** By using these radiation protection principles, emergency department personnel can adequately care for the patient's medical needs while minimizing their own radiation exposure. All activities should be guided by the ALARA concept.

There are three basic radiation protection principles that can be employed to reduce exposure to ionizing radiation. These principles are based on consideration of three radiation protection factors that alter radiation dose: time, distance and shielding.

Time. Time is an important factor in radiation protection. This principle states that the shorter the time spent in a radiation field, the less radiation is absorbed by the body. Depending on the activity present, radioactive material will emit a certain amount of radiation per unit time. Obviously, the longer a person remains in a radiation field, the more radiation the person will absorb into the body.

Distance—Inverse Square Law. The inverse square law states that the radiation dose rate changes inversely by the square of the change in the distance. For example: The dose rate at 3 feet is 20 R/hr. Increase the distance by a factor of 2 (to 6 feet), the dose rate decreases by a factor of 2^2 or 4, and the dose rate is 5 R/hr. Triple the distance from 3 to 9 feet, and the dose decreases by a factor of 3^2 or 9. The dose rate would then go from 20 R/hr to 2.2 R/hr. It also works in reverse—decrease the distance to ½, and the dose rate quadruples. Go from 6 to 3 feet, and the dose rate goes from 5 to 20 R/hr. The farther a person is from the source of radiation, the lower the radiation dose.

Shielding. The denser a material, the greater is its ability to stop the passage of radiation. In most cases, high-density material such as lead is used to shield from radiation. Portable lead or concrete shields are sometimes used when responding to accidents where contamination levels are very high. Some specialty centers for radiation accident management have constructed shielded surgical tables for protection. In emergency management of the contaminated patient, shielding is limited to standard surgical clothing with slight modifications. Surgical clothing will protect the individual against contamination and will also stop the passage of all alpha and some beta radiation. However, it does not stop penetrating gamma radiation. In the hospital emergency department, shielding is limited to anti-contamination measures, and the principles of time and distance are used to reduce radiation exposure. Lead aprons used by X-ray departments are only partially effective as they are too thin.

Emergency Response Exposure Limits

The following are the recommended dose limits for workers performing various emergency services as defined by EPA. These are legally established limits. They should not be considered safe limits that can be accumulated with impunity, because they still contain some risk. Strive to maintain ALARA.

Recommended EPA Limits

The recommended dose for emergency response efforts is a total dose of no more than 25 rems for any single life-threatening emergency. Your facility may mandate even lower levels.

What is the total dose exposure approved by your facility?

Emergency Response Exposure Limits		
Dose Limit (REM)	**Activity**	**Condition**
5	All	
10	Protecting valuable property	Lower dose not practical.
25	Lifesaving or protection of large populations	Lower dose not practical.
>25	Lifesaving or protection of large populations	Only on a voluntary basis to persons fully aware of the risks involved.
Source: EMI/FEMA. 1994. *Fundamentals for Radiological Response Team* Course		

Yearly Maximum Permissible Dose for Radiation Workers

The Nuclear Regulatory Commission sets yearly radiation exposure limits for various categories of exposed persons. These are legal limits that are not to be exceeded at any time. These limits are published in the 10 Code of Federal Regulations 20, Occupational Limits for External Exposure.

Yearly Maximum Permissible Dose for Radiation Workers	
Whole Body	5 rem
Hands, forearms, etc.	75 rem
Skin of the whole body	30 rem
Pregnant radiation worker (fetus)	0.5 rem for single exposure
Non-radiation worker on public	0.1 rem
Source: EMI/FEMA. 1994. *Fundamentals for Radiological Response Team* Course	

Exercise: Are You in Danger?

Purpose: To check whether you can apply the basic concepts of radiation protection.

Directions: Answer each question. Check your answers in Appendix B. If you missed any items, review this section before continuing on to the next unit.

True or False

____1. The longer a person remains in the radiation field, the more radiation dose the person will accumulate.

____2. Surgical clothing will stop the penetrating gamma radiation.

____3. Lead is not an effective shield against alpha radiation.

____4. The quantity of radiation has little effect on the exposure rate from a given radioactive material.

____5. The radiation dose rate increases as your distance from the source decreases.

Types of Radiological Instruments

Human senses do not respond to ionizing radiation, so special instrumentation must be used for radiation detection and measurement. Radiation is detected through instruments such as survey meters or dosimeters. Typical radiation instruments will not detect some of the radionuclides commonly used in medicine, industry, and research, regardless of the amount present inside or spilled from the package. On the other hand, for some radionuclides, even for relatively small amounts in intact packages, the instruments can respond very well. The “None, Some, Good Table” in Appendix C identifies the response capabilities of two commonly used survey instruments for 350 radionuclides. This table applies to the Civil Defense instruments CD V-700 and CD V-715 only. You will learn more about how to read and interpret meters and dosimeters in the classroom course.

Survey Meters (such as CD V-700 and CD V-715)

Survey meters measure **exposure rate** or the intensity of the radiation at the location at some point in time. All radiological survey instruments are rate meters—they read out exposure per unit of time. The survey meter can be compared to a speedometer of a car; both measure relative to time. The survey meter measures radiation exposure rate in roentgens per hour like the speedometer of an automobile records the rate of travel in miles per hour.

The two most commonly used radiation monitoring instruments are the Geiger-Mueller (GM) or Geiger counter, and the ionization chamber. Each of these instruments detects radiation by detecting charged particles (ions) produced by ionizing radiation. The Geiger-Mueller counter is designed to detect low-level radiation, while the ionization chamber is designed for both medium- and high-level measurements. The survey instruments most likely to be available are the CD V-715 ionization survey meter and the CD V-700 G-M survey meter. There are a variety of commercially available instruments, and staff should become familiar with the instruments used in their facility.

Dosimeters, Film Badges, Thermoluminescent dosimeters (TLDs)

The dosimeter measures the total amount of radiation to which you were exposed. These devices are commonly called pocket chambers, pocket dosimeters, and pencil dosimeters. Two commonly distributed Civil Defense meters are the CD V-138 and CD V-742.

Dosimeters are calibrated in roentgens (R) or milliroentgens (mR). The dosimeter can be compared to the odometer in a car. The dosimeter measures the radiation exposure in roentgens or milliroentgens and is like the mileage indicator (odometer) which records the total miles traveled.

The CD V-742 measures gamma exposure to 200 roentgens or 200,000 milliroentgens. It is intended for measuring high levels of exposure. The CD V-138 measures relatively low levels of exposure and has a maximum scale reading of 200 milliroentgens. The CD V-730 has a range of 0 to 20 roentgens, and the CD V-740 (silver clip) has a range of 0 to 100 roentgens. Dosimeters of this type are made to be read directly at the time of the incident without the need to be developed or processed.

A film badge consists of a piece of photographic film in a special holder. It is used to monitor whole-body radiation dose.

The thermoluminescent dosimeter (TLD) is another type of dosimeter that measures the total dose accumulated over the period of exposure.

Film badges and TLDs provide a permanent record of the dose received, but must be processed at a remote site to be read.

Limitations of the Meters

Few of the survey meters can detect or measure alpha or low energy beta radiation without special probes. Many of the meters may not have been properly maintained or calibrated. Personnel must be familiar with the limitations of the types of instruments that they will be using.

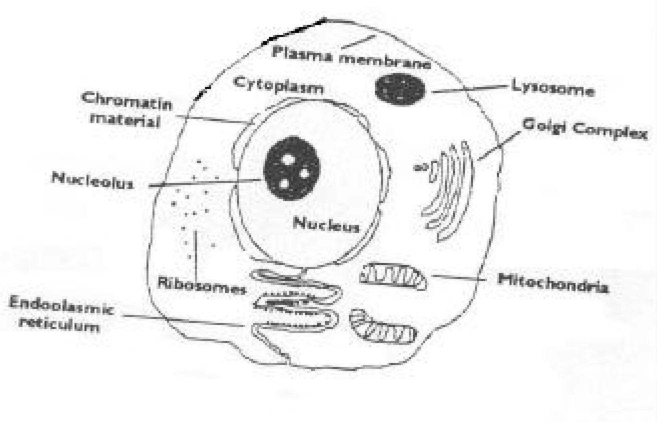
Radiation Biology

The biological effects of ionizing radiation are caused by the absorption of radiation energy in the body and distribution of that energy in the body. It is important to understand how radiation affects individual cells within the body. If radiation were to pass straight through living material without leaving any energy behind, it would have no biological effect. The following are basic concepts about cell structure to help understand the effects of radiation on the body.

Basic Concepts of Cell Structure

Cells are the smallest structures capable of maintaining life in humans. They are the living units of the body. Many cells together make up organs, which make up systems, which make up the entire organism. Intercellular supporting and connecting structures connect the cells. Each of the approximately 75 trillion cells in the body performs a specific function. All cells require nutrition and oxygen. This allows for the use of energy to carry out the functions of the cell. All cells also must have the ability to excrete and eliminate waste products. Additionally, cells must have the ability to reproduce, although this may be lost in the maturation process, as in neurons.

The internal environment of the cell consists of the nucleus, the cytoplasm, water, electrolytes, proteins (both structural and enzymes), lipids, and carbohydrates, as shown in the diagram below.



Cell Membrane. Membranes line the cell itself and the structures contained within it. These membranes are not identical but tend to be similar in structure. The cell membrane, or the membrane that contains the entire cell and its contents, consists mostly of lipids with some proteins. The cell membrane is not just an inert bag. It is alive and has many functions, such as controlling what enters and exits the cell, has receptors for hormones, etc. The membrane consists of a bilipid layer with embedded proteins.

Cytoplasm. Cytoplasm is a semi-liquid material that composes cells. It has various specialized structures floating in it and is mostly water.

Nucleus. The nucleus is the largest structure of the cell. It contains chromosomes that carry the cell's genetic information.

DNA and Chromosomes. DNA carried in the chromosomes is the critical site of radiation damage in a cell. It carries, in code form, all of the blueprints that specify a human being: the well-developed brain, the sensitive finger, and the upright stance. It also carries the instructions for the activities and the structure of the cell. The chromosomes are long thread-like structures made up of a complex material called DNA, which is a very long molecule.

DNA is a very large, tightly-coiled, double-stranded molecule that is sensitive to radiation damage. This macromolecule contains the genetic information. The structure of DNA is similar to a ladder. The rungs are made of specific, different molecules (2 required to make a rung), and the sequence of the rung molecules caries the genetic information. Radiation effects can range from complete breaks of one or both of the side chains of the DNA, to point mutations that are essentially radiation-induced chemical changes in the nucleotides that may not affect the integrity of the basic structure, but will change the information coded on the DNA. Mechanisms exist for repair of some types of damage. Other types, such as double strand breaks, have no accurate mechanism for repair.

Types of Cell Damage

When radiation strikes living cells, the radiation energy is transferred to the atoms of the cell, causing chemical changes (ionization) that may be harmful to the cell. The radiation damaged cell can have one of 3 outcomes.

Cell Survives. When there is no damage, or the damage is fully repaired, the cell is not harmed and survives.

Functional Impairment. Damaged cells can be functionally damaged and be unable to carry out their functions, or they may undergo transformation to a cancer cell. This damage may not appear immediately, but may occur over a long period of time.

Cell Death. Most organs have a fairly large reserve capacity. Killed cells are replaced quickly in most tissues with any degree of reserve capacity, and do not cause significant overall clinical effects unless the cells involved are highly critical or the fraction of cells killed in a given organ is large. In some cases, the immature precursor cells that produce the functional, mature cells are more radiosensitive than the mature cell. One instance is the bone marrow, where the stem cells are much more radiosensitive than the mature red blood cells or the granulocytes. For this reason, it can take days to weeks for the damage to become clinically apparent. If sufficient numbers of cells die, the structural or functional integrity of an organ is affected.

Tissue Sensitivities

The amount of radiation-induced damage to tissues is influenced by the tissue sensitivity.

Most Sensitive

The most sensitive tissues are:

- Lymphocytes
- Bone marrow stem cells
- Small intestine epithelium

Some tissues, such as the epithelial lining of the gastrointestinal tract, and the hematopoietic system in the bone marrow, maintain a continuous high cell turnover rate. Thus, the stem cells are almost all relatively sensitive to radiation. These tissues normally contain cell populations in all stages of maturation and differentiation from primitive stem cells to mature functional cells. Bone marrow has a large reserve capacity in adults. In general, sensitivity to ionizing radiation is higher in immature, primitive and rapidly reproducing cells such as bone marrow stem cells and intestinal epithelial cells. Mature cells, and cells that do not reproduce are more resistant to the effects of radiation. One exception is mature lymphocytes, which are mature cells that do not reproduce, but are exceptionally sensitive to the effects of radiation.

Least Sensitive

The least sensitive tissues are:

- Central nervous system
- Bone cells
- Muscle cells

These cells are mature functional cells that are relatively resistant. The functional cells of the central nervous system (neurons) are not replaced if lost or destroyed.

Mechanisms of Biological Damage

Biological damage can occur through direct and indirect action.

Direct Action

The direct action mechanism occurs because of direct insult to a biological molecule by ionizing radiation and the consequent break-up of the molecule. The chromosomes are the critical site of radiation damage in a cell.

Indirect Action

The indirect mechanism occurs when water in the body is irradiated. The water molecule is split and the resulting free radicals or peroxides will then damage the cell.

Factors Affecting Biological Damage

Total Dose, as you learned earlier, is the quantity of radiation absorbed. The greater the dose, the greater the damage.

Dose Rate. Biological systems have mechanisms for repair of damage caused by radiation. All of these mechanisms have a saturation point, however. If the dose rate is low enough that the repair mechanisms can keep up, most of the damage will be repaired and clinical effects will be minimized. Theoretically, the damage should be zero in this case, but no biological system is perfect, and repairs will occasionally be faulty, or damage will escape repair. Any damage to the genetic material that is present at replication will be passed on. If the dose rate is such that the damage rate outstrips the repair rate, then damage will accumulate.

Type and Energy of Radiation. Alpha radiation does not penetrate the skin, so it is not a hazard if the source is outside the body. If internalized, however, it transfers its energy in a short distance, doing a great deal of damage. If the alpha particle is released next to a cell's nucleus, a great deal of damage can be done to the genetic material. Beta radiation is a hazard to the skin if external, but will not damage the internal organs unless the source is taken internally. It does not transfer its energy in as short a distance as alpha, but will do a significant degree of damage. Gamma radiation will penetrate deeply from externally or internally, reaching deep organs. Generally, the greater the energy of the radiation, the greater the damage it will do.

Portion of Body Exposed. Different tissues have different sensitivities to radiation (bone marrow, gut, epithelium are most sensitive; bone, brain, etc. are least sensitive). If the portion of the body exposed contains sensitive tissue, then the degree of damage will be higher than if it contains a less sensitive tissue. An isolated limb can tolerate a much greater exposure than the trunk. The greater the percent of the body exposed, the less tolerated the damage. This would be analogous to a crushed small toe being much better tolerated than a crushed leg.

Biological Variability (age, general health, etc.). The extremes of age are the most sensitive to damage due to radiation. The young are sensitive due to their high rate of growth and cell division; the elderly are sensitive to radiation damage due to their generally poorer reserves and their decreased ability to handle biological stress. People who are in better general health will have a greater ability to tolerate radiation or any other biological stress.

Availability of Treatment. As with any disease or injury, greater quantity and sophistication of treatment leads to a better outcome. This becomes more important in incidents involving a large number of patients (mass casualty incidents), and incidents that occur in less developed countries.

Clinical Effects of Radiation

Acute Radiation Syndrome (ARS)

Acute radiation syndrome (ARS) is a disease state that occurs in stages over hours to months as damage to organs and tissues is expressed. It can be further divided into the hematopoietic, the gastrointestinal, and the cardiovascular/central nervous system syndromes based on the clinical picture. This group of signs and symptoms develops as a result of an acute, or in some cases subacute, exposure of the whole or a significant portion of the body to an appreciable dose (> 100 REM) of ionizing radiation. The syndrome is a clinical manifestation of the responses of the individual constituents of the body systems to an acute exposure to radiation. The clinical course is predictable and is divided into prodrome, latent, manifest illness, and recovery or death phases that are of variable duration (a few hours to several weeks), depending on the nature of the exposure. A general rule of thumb is that the higher the dose, the more rapid the onset of symptoms, the shorter each phase will be, and the more intense the symptoms. For example, the patient who develops mild nausea several hours after the exposure has probably received a fairly low dose, while the patient who develops severe vomiting and diarrhea within several minutes of the exposure has received a very high, probably fatal dose. These observations can be used to make very rough initial dose estimations. The $LD_{50\text{-}60}$ is about 450 RAD. $LD_{50\text{-}60}$ is the dose at which 50 percent of the people exposed will be expected to die within 60 days of exposure without treatment.

ARS—Prodrome Phase is the first phase of ARS. It consists of non-specific symptoms such as malaise, anorexia, nausea, vomiting and possibly diarrhea. Onset will be in minutes to hours to a day or more, and lasts hours to days. This is the phase during which emergency department and field personnel will see these patients. The more intense and the more rapid the onset, the greater the dose.

ARS—Latent Stage is the second stage of ARS. The symptoms of the prodrome phase resolve except for some mild weakness. This stage will last for hours to days to a few weeks. In general, the shorter the latent stage, the greater the dose.

ARS—Manifest Illness Stage is the third stage. This is the stage where the damage to the organs and tissues becomes manifest. It is further divided into 3 syndromes based on the clinical picture as outlined below.

Hematopoietic Syndrome. Occurs in doses in the 1-8 Gy range.

The prodrome consists of anorexia, nausea, vomiting and possibly diarrhea, and may take up to 2–4 hours to 1-2 days to begin. The latent phase lasts 3-4 weeks and progresses to the manifest illness stage.

The patient will become severely ill as the damage to the bone marrow becomes clinically apparent. The clinical picture is one of bone marrow suppression with leukopenia (low white blood cell count), thrombocytopenia (low platelet counts) and anemia. Serious, difficult to treat infections, anemia, difficult to control bleeding, poor wound healing, etc. will result. These patients require intensive treatment and possibly bone marrow stimulating factors or bone marrow transplants.

Gastrointestinal Syndrome. Occurs in doses in the 8-30 Gy range.

The prodrome consists of severe nausea, vomiting with watery diarrhea onset within 1–3 hours or less. The latent phase may last 5-7 days, and is followed by the manifest illness phase. The patient will develop a return of severe nausea, vomiting and diarrhea, likely bloody with fever. The clinical picture is one of significant damage to the gastrointestinal tract, mainly the small intestine lining. The epithelial lining of the gut is depleted, leading to invasion of gut bacteria into the wall of the intestine, and then into the blood as well as bleeding from these denuded areas. Absorptive capacity is also lost, leading to malnutrition, dehydration and electrolyte disturbances. The doses that produce the gastrointestinal syndrome are higher than those required to produce the hematopoietic syndrome; therefore, these patients will also sustain extensive the bone marrow damage characteristic of the hematopoietic syndrome. Their condition will be further complicated by the resultant infections from gut bacteria, as well as the bleeding from the gut being made more difficult to control by the falling white blood cell and platelet counts, and the anemia. These patients will require very intensive treatments if they are going to survive, and many will eventually die of their illnesses.

Cardiovascular/Central Nervous System (CV/CNS) Syndrome. Occurs at doses over 30 Gy.

The prodrome consists of a rapid onset of severe nausea, vomiting and diarrhea followed rapidly by confusion, seizures, coma, and hypotension progressing to death within 24–48 hours. If present, the latent phase will also be very short. These doses are high enough to produce damage to the radioresistant central nervous system and cardiovascular system. Doses of this magnitude are essentially universally fatal.

ARS—Recovery or Death is the fourth and final stage during which the patient either recovers, or dies from injuries sustained.

Treatment of the Acute Radiation Syndrome

As emergency department and field personnel will be treating patients during the prodrome phase if they see the manifestations of ARS at all, treatment will be mainly symptomatic. Measures such as IV fluids to replace fluid losses from vomiting and diarrhea, antiemetics to control nausea and vomiting and other comfort measures are indicated. Further treatment of ARS, as well as treatment of contamination and incorporation, are beyond the scope of this course, and will be covered in the classroom course.

Treatment Priorities

In the treatment of the patient involved in a radiological accident, the treatment of conventional (non-radiological) traumatic and medical problems takes precedence over treatment of the radiological injuries. ARS is rarely a life-threat in the E.D. If it is, the patient has most likely received a fatal dose for which there is no effective treatment beyond comfort measures. Conventional life-threats, such as a tension pneumothorax, however, are treatable and survivable, making these first priority.

Dose Estimation

There are several methods to determine the dose of ionizing radiation that a patient has received. The most accurate would be to read the dose off of a dosimeter if the patient were wearing one at the time of the exposure. If not, there are other methods to estimate dose.

1. **Clinical Effects** As stated above, the intensity and rapidity of onset of symptoms is related to the dose, and this can be used to estimate the dose received.
2. **Cytogenetic Dosimetry** Some type of damage to the chromosomes is characteristic of ionizing radiation. Blood can be drawn from the patient, and the number of these damaged chromosomes can be used to estimate the dose received.
3. **Absolute Lymphocyte Count (ALC)** The ALC at 48 hours can be used to estimate the severity and lethality of the dose received.

Chemical Hazards

There are other hazards associated with radiation. For instance, a radioactive substance may also be corrosive, flammable, or toxic. In fact, it is possible that these hazards may pose a greater threat than the ionizing radiation. The hazards may occur because of direct exposure or through the interactions of the materials with each other or with a radioactive material.

Exposure to chemicals can be acute or chronic. Acute means a single dose or exposure, whereas chronic means repeated exposure. Exposure may be local or systemic. Local means that the chemical attacks at the site of exposure. Systemic means that the chemical must pass through the skin, mucous membranes, or lungs and will move through the bloodstream.

Chemicals do not present any fixed symptoms that are unique to all chemical exposures; instead, symptoms of exposure to each type of chemical vary considerably. The following table lists some of the effects of chemical hazards on the body.

Effects of Chemicals on the Body	
Systems	**Symptoms**
• Lungs	• Eye irritation
• Nervous system	• Respiratory (lungs) distress
• Hepatic (liver)	• Asphyxiation
• Hematic (blood)	• Unconsciousness
• Kidneys	• Fatigue, exhaustion, irritability
• Skeletal (bones)	• Headaches
• Dermal (skin)	• Nausea

Nature of Chemical Hazards

The hazards posed by chemicals vary and pose many kinds of threats and problems. Chemicals can occur as aerosol, dust, fumes, gas, smoke, and vapors. For example, hazards can occur when radioactive materials combine with flammables or explosives. In such situations, chemicals will intensify a fire and will cause the release of more radioactive material. Many radioactive materials are shipped as corrosives. The toxic gas uranium hexafluoride is more hazardous than the uranium radiation. Shipments of uranium hexafluoride can have both "radioactive" and "corrosive" labels. Metals such as uranium and plutonium are heavy metals and will have toxic effects similar to other heavy metals such as lead and mercury.

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UNIT 5: POST-TEST

Directions: Answer each question. Each answer counts 10 points. Check your answers in Appendix B. If you missed any items, review this unit before taking the final examination.

1. John used a survey meter to measure the amount of radiation present and found none. Later, Sue used a different same meter and found significant amounts of radiation. What could have caused the differences in the readings?
   a) John's meter was not working properly.
   b) Radiation had time to register in the body because of the time that passed between the two readings.
   c) Sue's body or clothing were contaminated with radioactive material.
   d) John did not use the proper type of meter to detect the type of radiation being emitted.

2. Which of the following would expose deep organs to radiation?
   a) Chest X-rays
   b) Gamma rays
   c) Beta particles
   d) Alpha particles

3. Which of the following is the highest source of radiation (on an annual basis)?
   a) Living in Chicago
   b) X-rays and nuclear medicine
   c) Living near a nuclear power plant
   d) Radon in an average household

4. What is the largest source of man-made radiation?
   a) Radiation used in medicine
   b) Nuclear power plants
   c) Scientific research
   d) Mining

5. Which of the following takes priority in the treatment?
   a) Nausea and vomiting caused by exposure to 15 Gy external irradiation.
   b) Tension pneumothorax.
   c) Superficial leg laceration.
   d) Decontamination

6. Which of the following particles pose an external and internal hazard?
   a) Beta particles
   b) Alpha particles
   c) Beta and gamma particles
   d) Electrons

7. The rad, rem, and gray are measures of what?
   a) Absorbed Dose
   b) Units of Exposure
   c) Amount of Radioactivity
   d) Degrees of radiation

8. An important goal of emergency responders in dealing with radiation-related incidents is to:
   a) Protect the public
   b) Save lives
   c) Keep their own radiation exposure ALARA
   d) Treat all patients as emergency care victims

9. What is the EPA recommended maximum dose limit for any single life-threatening emergency?
   a) 5
   b) 10
   c) 25
   d) 50

10. What happens at the fourth stage in the acute radiation syndrome?

    a) Recovery or death
    b) Nausea and diarrhea
    c) Weakness
    d) Gastrointestinal syndrome